SNS 104020000-PN0003 R00

Coupled Cavity Linac Module 4 and Superconducting Linac Beam Commissioning Plan

July 2005

A U.S. Department of Energy Multilaboratory Project

SPALLATION NEUTRON SOURCE

Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory

SNS

by

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Beam Commissioning Plan

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1. INTRODUCTION

This document presents the beam commissioning plan for the Coupled Cavity Linac module four and the Superconducting Linac portions of the SNS linear accelerator. The accelerator system for this commissioning run consists of the Front-End Systems (FES) , Drift Tube Linac Tanks 1,2,3,4,5, and 6 (DTL1-6), Coupled Cavity Linac Modules 1,2,3, 4 (CCL1-4) the medium beta Superconducting Linac (SCL) cryomodules 1-11, the high beta superconducting cryomodules 12-22, a retractable beam stop and the Linac Beam Dump (LBD). Each medium beta cryomodule contains 3 cavities and each high beta cryomodule contains 4 cavities. The FES and DTL linac, and CCL modules 1,2 and 3 have been commissioned already.

1.1 SYSTEM LAYOUT AND CONFIGURATION

1.1.1 CCL module 4 and the SCL Linac.

CCL module 4 and the SCL linac are shown in Figure 1. The Front-End Systems, DTL and CCL1-3 are identical to that which was commissioned earlier. CCL4, the medium beta SCL, the high beta SCL and the linac beam dump are new hardware which will be commissioned with beam for the first time. The basic parameters for CCL module 4, the SCL medium beta section and SCL high beta section components are given in Table 1. The CCL module 4, the SCL medium beta section and SCL high beta section output beam parameters are summarized in Table 2. This table shows both the design parameters, where applicable, and the performance goals that we would like to achieve during beam commissioning. Note that the SCL output performance goal energies are not the same as the design values, since the cavity gradients are not exactly the same as the design values. This is a reflection of the flexibility of the SCL design.

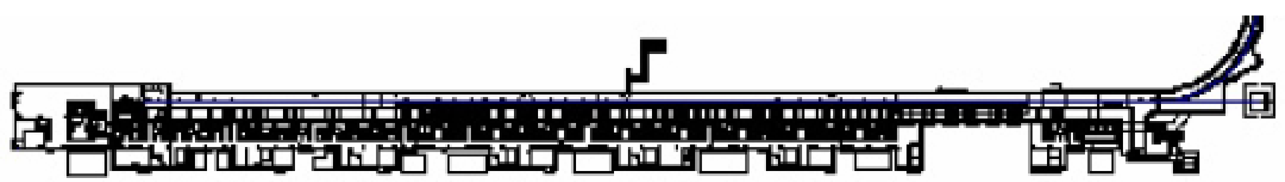

Figure 1. Layout of the SNS linac: Front End, DTL, CCL, SCL and HEBT line transport to the linac dump.

Table 1a. Coupled Cavity Linac Module 4 Design Parameters	
Resonant Frequency	805 MHz
Bore radius	15 mm
Tank Length	14.995 m
Number of cells	96 in 12 segments
Energy Gain	28.412 MeV
Stored Energy	9.41 J
Synchronous phase	-28°
Average E_0T	2.413 MV/m
Shunt Impedance (design/measured) ZT^2	27.29 / 29.523 MΩ/m
Unloaded Quality Factor (design/measured)	19311/20891
External Quality Factor (design/measured)	13975/16984
Peak RF Structure Power	2333 kW
Focusing structure	FODO
Focusing period	13 $\beta\lambda$
Table 1b. Medium Beta SCL Design Parameters	
Resonant Frequency	805 MHz
Active cavity Length	0.682 m
Number of cells per cavity	6
Average E_0T (design)	9.2 – 11.2 MV/m
R_{shunt}/Q_0 (design)	220-440
Unloaded Quality Factor (design)	> 5 x 10^9
Available klystron power per cavity	408 kW
Cavities per cryomodule	3
Focusing structure	Doublet
Focusing period	5.839 m
Limiting aperture in warm section (mm)	70 mm
Table 1c. High Beta SCL Design Parameters	
Resonant Frequency	805 MHz
Active cavity Length	0.906 m
Number of cells per cavity	6
Average E_0T (design)	12.2 – 16.6 MV/m
R_{shunt}/Q_0 (design)	170 - 570
Unloaded Quality Factor (design)	> 5 x 10^9
Available klystron power per cavity	522 kW
Cavities per cryomodule	4
Focusing structure	Doublet
Focusing period	7.891 m
Limiting aperture in warm section (mm)	70 mm

Table 2a. CCL module 4 output beam parameters

Parameter	Design Value	Performance Goal
Input Energy [MeV]	157.2143	157.21± 0.03*
Output Energy [MeV]	185.6266	185.62± 0.03*
Peak Macropulse Current [mA]	38	> 38
Beam pulse length [msec]	1.0	≤ 0.05
Repetition Rate [Hz]	60	≤1
Duty Factor [%]	6	<.005
Chopped Beam Gap [%]	32	32
Transverse jitter and variation within a pulse [mm]	N/A	< 0.1
Energy jitter and variation within a pulse [MeV]	N/A	< 0.1*
Phase jitter and variation within a pulse [deg]	N/A	< 2.0
Tank 4 Beam loss	< 8 W	< 4% (measurable loss threshold)

Table 2b Medium beta SCL output beam parameters

Parameter	Design Value	Performance Goal
Input Energy [MeV]	185.627	185.627± 0.03*
Output Energy [MeV]	391.433	> 380
Peak Macropulse Current [mA]	38	38
Beam pulse length [msec]	1.0	≤ 0.05
Repetition Rate [Hz]	60	≤1
Duty Factor [%]	6	<.005
Chopped Beam Gap [%]	32	32
Transverse jitter and variation within a pulse [mm]	N/A	< 0.1
Energy jitter and variation within a pulse [MeV]	N/A	< 0.1-0.4*
Phase jitter and variation within a pulse [deg]	N/A	< 2.0
Medium beta section Beam loss (warm sections)	< 2 W	< 1 W/m

Table 2c . SCL High Beta output beam parameters

Parameter	Design Value	Performance Goal
Input Energy [MeV]	391.433	> 380
Output Energy [MeV]	1000.559	> 900
Peak Macropulse Current [mA]	38	< 20
Beam pulse length [msec]	1.0	≤.05
Repetition Rate [Hz]	60	≤1
Duty Factor [%]	6	<.005
Chopped Beam Gap [%]	32	32
Transverse jitter and variation within a pulse [mm]	N/A	< 0.1
Energy jitter and variation within a pulse [MeV]	N/A	< 0.3-1.5*
Phase jitter and variation within a pulse [deg]	N/A	< 2.0
High beta section Beam loss (warm sections)	< 3 W	< 1 W/m

* Limited by measurement accuracy

1.1.2 Beam stops

The same Faraday Cups used in the previous DTL-CCL beam commissioning will be used in this commissioning run in a similar fashion. The retractable beam stop after CCL4, new to this run, can accept an average power of 500 kW or 500 J/pulse, which corresponds to a 40 mA beam for 50 μs at 1.5 Hz and 157 MeV.

When commissioning the SCL, the beam will be transported from the SCL through the first part of the HEBT transport line and then though the linac dump transport line to the linac dump. The linac beam dump will be available and will be used for all beam commissioning activities, downstream of CCL module 3. The linac beam dump is not actively cooled, but is capable of an average power of 7.5 kW.

1.1.3 Diagnostic Systems

The front-end systems, DTL and CCL diagnostic suite is the same that used in the previous commissioning runs. Table 3 lists the additional diagnostics that will be available for SCL commissioning. In the SCL, the warm sections between the cryomodules contain a BPM, and nine of the warm sections are equipped with a laser wire box for transverse profile measurements. There are no interceptive diagnostic devices in the superconducting linac section. There are conventional wire profile devices downstream of the SCL in the HEBT and Linac Dump transport lines that will be used. The Machine Protection System (MPS) ensures that these wire scanner devices can be operated only in the appropriate machine mode to avoid damage to the devices. The power limitations for the warm linac intercepting diagnostics are listed in Table 4.

Table 3 Diagnostics for SCL Commissioning

	BPM	WS	BCM
Medium beta SCL	13	4	1
High beta SCL	21	5	0
HEBT (through HEBT_Mag:D11)	11	5	2
Linac Dump	6	1	0

Table 4. Beam power capabilities of the diagnostic systems*

System	Peak Current (mA)	Maximum Pulse Length (μs)	Maximum Repetition Rate (Hz)
MEBT Wire Scanners	50	50	5
MEBT Aperture	38	50	30
DTL and CCL Wire Scanners	38	50	5

*Longer pulse lengths are acceptable at lower peak current, such that the product of current and pulse length is maintained within the value shown in the table.

1.2 COMMISSIONING GOALS

The primary beam commissioning goals are the following:

- Bring CCL segment 4, the SCL medium beta and high beta cryomodules and all associated sub-systems into beam operation
- Characterize the primary beam parameters and achieve the beam performance goals outlined in Table 2
- Develop and validate procedures which will be used for tuning during operations
- Characterize the beam performance versus tuning variables
- Measure losses consistent with the measurable loss limit.
- Measure pulse-to-pulse jitter in beam parameters

If time permits we would like to accomplish several secondary goals, namely

- Explore production beam parameters independently
- Loss study with matching
- Test the energy management and automatic SCL RF setup applications
- Test the MEBT laser wire system
- MEBT scraper experiment

1.3 COMMISSIONING BEAMS

We plan to use unchopped beam for the bulk of the commissioning studies. The beams will be consistent with the beam-handling capabilities of the diagnostics systems in use at the time.

1.3.1 Peak Current

We plan to perform the initial commissioning studies with a 10 mA peak current beam. This low current can be easily achieved with the use of the MEBT beam limiting apertures, and can be tuned to provide a relatively flat profile over the short pulse length we will use (see below). The low current is chosen to minimize dose and activation during initial commissioning. Once the initial linac setup is done, we will increase the current to 20 mA, and finally 38 mA.

1.3.2 Pulse Length

The pulse length will be set typically by the limitations of the diagnostic system and beam stop in use at the time, and a general desire to minimize beam loss during tuning. For the initial CCL 4 module and SCL cryomodules commissioning, we will use a pulse length $\leq$ 20 μsec.The MPS pulse width key will be always in 50 μsec position to prevent accidental run at larger pulse width.

1.3.3 Repetition Rate

All of the commissioning program will be carried out at low repetition rate equal or less than 1 Hz. “Beam on demand” mode will be used whenever possible and appropriate in order to minimize activation of the hardware by high energy beam. A single beam macro-pulse is accelerated upon request in this mode.

2. BEAM OPTICS

2.1 NOMINAL OPTICS

The nominal beam envelopes are shown in Figure 3 for 20 mA operation. The nominal SCL through Linac dump quadrupoles settings are given in Table 5a, and anticipated RF setpoints in table 5b. Nominal phase settings for SCL cavities will be found using proper tuning algorithms with beam. The amplitudes will be set based on cavity performance capability, and the amplitude value will be calibrated with beam based applications.

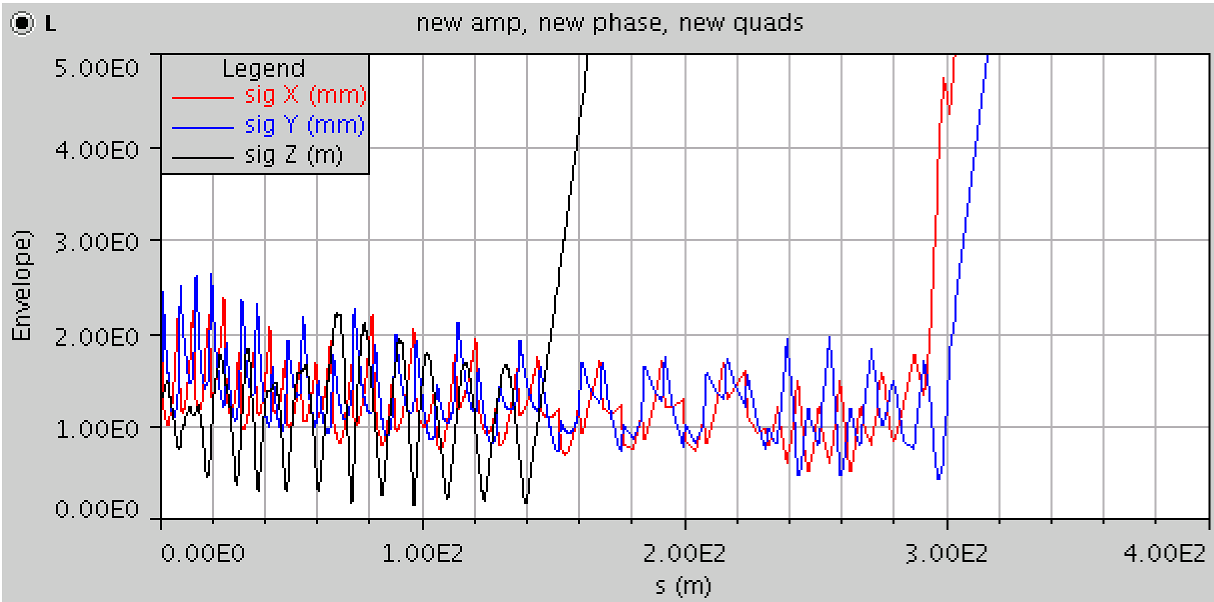

Figure 3. On-line model beam envelope profiles in the SCL through linac dump, for 20mA operation.

Table 5a. SCL through linac dump quadrupole field (T/m) settings for 20 mA operation, using measured SCL cavity performance.

SCL_Mag:QH00	-17.890
SCL_Mag:QV00	16.880
SCL_Mag:QH01	-4.450
SCL_Mag:QV01	4.450
SCL_Mag:QH02	-4.435
SCL_Mag:QV02	4.435
SCL_Mag:QH03	-5.237
SCL_Mag:QV03	5.237
SCL_Mag:QH04	-5.290
SCL_Mag:QV04	5.290
SCL_Mag:QH05	-5.424
SCL_Mag:QV05	5.424
SCL_Mag:QH06	-5.542
SCL_Mag:QV06	5.542
SCL_Mag:QH07	-5.591
SCL_Mag:QV07	5.591
SCL_Mag:QH08	-5.607
SCL_Mag:QV08	5.607
SCL_Mag:QH09	-5.470
SCL_Mag:QV09	5.470
SCL_Mag:QH10	-5.317
SCL_Mag:QV10	5.470
SCL_Mag:QH11	-6.094
SCL_Mag:QV11	6.029
SCL_Mag:QH12	-6.185

SCL_Mag:QV12	6.185
SCL_Mag:QH13	-6.533
SCL_Mag:QV13	6.533
SCL_Mag:QH14	-6.664
SCL_Mag:QV14	6.664
SCL_Mag:QH15	-6.836
SCL_Mag:QV15	6.836
SCL_Mag:QH16	-6.885
SCL_Mag:QV16	6.885
SCL_Mag:QH17	-6.889
SCL_Mag:QV17	6.889
SCL_Mag:QH18	-6.762
SCL_Mag:QV18	6.762
SCL_Mag:QH19	-6.710
SCL_Mag:QV19	6.710
SCL_Mag:QH20	-6.650
SCL_Mag:QV20	6.650
SCL_Mag:QH21	-6.550
SCL_Mag:QV21	6.550
SCL_Mag:QH22	-6.247
SCL_Mag:QV22	6.247
SCL_Mag:QH23	-6.010
SCL_Mag:QV23	6.010
SCL_Mag:QH24	-6.010
SCL_Mag:QV24	6.010
SCL_Mag:QH25	-5.967
SCL_Mag:QV25	5.967
SCL_Mag:QH26	-5.967
SCL_Mag:QV26	5.967
SCL_Mag:QH27	-5.967
SCL_Mag:QV27	5.967
SCL_Mag:QH28	-5.967
SCL_Mag:QV28	5.967
SCL_Mag:QH29	-5.967
SCL_Mag:QV29	5.967
SCL_Mag:QH30	-5.114
SCL_Mag:QV30	4.859
SCL_Mag:QH31	-5.408
SCL_Mag:QV31	5.521
SCL_Mag:QH32	-4.243
SCL_Mag:QV32	5.360
SCL_Mag:QH33	-4.243
HEBT_Mag:QV01	3.921
HEBT_Mag:QH02	-3.921
HEBT_Mag:QV03	3.921
HEBT_Mag:QH04	-3.921
HEBT_Mag:QV05	3.921
HEBT_Mag:QH06	-3.921
HEBT_Mag:QV07	3.921
HEBT_Mag:QH08	-3.358

HEBT_Mag:QV09	2.992
HEBT_Mag:QH10	-2.788
HEBT_Mag:QV11	2.334
LDmp_Mag:QH01	1.756
LDmp_Mag:QV02	2.888
LDmp_Mag:QV03	1.474
LDmp_Mag:QV04	0.199
LDmp_Mag:QH05	1.756
LDmp_Mag:QV06	1.474

Table 5b. SCL cavity phase and amplitude set points

Cavity	Cavity start phase (deg)	Cell avg phase (deg)	Field (MV/m)
SCL_RF:Cav01a	-79.474	-12.902	23.426
SCL_RF:Cav01b	-77.438	-17.807	15.227
SCL_RF:Cav01c	-75.935	-21.109	14.524
SCL_RF:Cav02a	-65.822	-16.210	18.741
SCL_RF:Cav02b	-49.232	-6.385	21.083
SCL_RF:Cav02c	-55.550	-18.887	16.164
SCL_RF:Cav03a	-42.437	-12.000	25.183
SCL_RF:Cav03b	-33.828	-11.464	26.354
SCL_RF:Cav03c	-27.730	-12.923	23.426
SCL_RF:Cav04a	-24.742	-16.027	18.975
SCL_RF:Cav04b	NA	NA	0.000
SCL_RF:Cav04c	-19.420	-15.639	19.443
SCL_RF:Cav05a	-12.220	-13.634	22.254
SCL_RF:Cav05b	-9.173	-15.653	19.443
SCL_RF:Cav05c	-2.210	-13.363	22.723
SCL_RF:Cav06a	4.560	-11.719	25.885
SCL_RF:Cav06b	6.894	-14.191	21.435
SCL_RF:Cav06c	12.512	-12.717	23.894
SCL_RF:Cav07a	15.257	-13.969	21.786
SCL_RF:Cav07b	17.104	-15.499	19.678
SCL_RF:Cav07c	22.528	-13.258	22.957
SCL_RF:Cav08a	21.596	-17.179	17.804
SCL_RF:Cav08	27.301	-14.066	21.669

b			
SCL_RF:Cav08c	30.559	-13.622	22.372
SCL_RF:Cav09 a	25.269	-21.215	14.524
SCL_RF:Cav09 b	29.747	-18.441	16.632
SCL_RF:Cav09c	31.257	-18.717	16.398
SCL_RF:Cav10 a	38.604	-13.356	22.840
SCL_RF:Cav10 b	37.094	-16.977	18.038
SCL_RF:Cav10c	36.092	-19.591	15.695
SCL_RF:Cav11 a	44.075	-13.294	22.957
SCL_RF:Cav11 b	NA	NA	0.000
SCL_RF:Cav11c	41.448	-17.770	18.858
SCL_RF:Cav12 a	-71.762	-11.817	17.310
SCL_RF:Cav12 b	-87.151	-29.275	15.673
SCL_RF:Cav12c	-84.329	-28.381	16.140
SCL_RF:Cav12 d	-74.325	-20.486	17.076
SCL_RF:Cav13 a	-74.092	-22.524	20.117
SCL_RF:Cav13 b	-75.996	-26.787	17.076
SCL_RF:Cav13c	-72.286	-25.168	18.129
SCL_RF:Cav13 d	-71.260	-26.265	17.427
SCL_RF:Cav14 a	-61.525	-18.904	23.977
SCL_RF:Cav14 b	-61.472	-21.610	21.053
SCL_RF:Cav14c	-56.214	-18.945	23.977
SCL_RF:Cav14 d	-51.899	-17.500	25.965
SCL_RF:Cav15 a	-48.315	-16.904	26.901
SCL_RF:Cav15 b	-50.012	-21.310	21.403
SCL_RF:Cav15c	-41.678	-15.549	29.298
SCL_RF:Cav15 d	-40.194	-17.007	26.784
SCL_RF:Cav16 a	-40.370	-19.691	23.158
SCL_RF:Cav16 b	-40.680	-22.081	20.702
SCL_RF:Cav16c	-35.152	-18.568	24.561
SCL_RF:Cav16 d	-35.619	-21.113	21.637
SCL_RF:Cav17 a	-36.060	-23.313	19.649

SCL_RF:Cav17b	-35.884	-24.687	18.596
SCL_RF:Cav17c	-26.183	-16.745	27.251
SCL_RF:Cav17d	-26.407	-19.032	23.977
SCL_RF:Cav18a	-45.244	-39.266	12.164
SCL_RF:Cav18b	-33.333	-28.232	16.374
SCL_RF:Cav18c	-24.599	-20.783	21.988
SCL_RF:Cav18d	-35.608	-33.069	14.152
SCL_RF:Cav19a	-20.410	-19.038	23.977
SCL_RF:Cav19b	-31.128	-31.088	14.971
SCL_RF:Cav19c	-19.614	-20.666	22.105
SCL_RF:Cav19d	-15.348	-17.887	25.497
SCL_RF:Cav20a	-17.966	-21.956	20.819
SCL_RF:Cav20b	-19.363	-24.507	18.713
SCL_RF:Cav20c	-12.690	-19.010	23.977
SCL_RF:Cav20d	-11.831	-19.482	23.392
SCL_RF:Cav21a	-18.808	-27.559	16.725
SCL_RF:Cav21b	-19.522	-29.075	15.906
SCL_RF:Cav21c	-9.609	-20.079	22.690
SCL_RF:Cav21d	-9.606	-21.184	21.520

3. COMMISSIONING TASKS

The list of commissioning tasks and the beam parameters required for each task are contained in Appendix A. The commissioning proceeds along the following broad outline, in which beam operation in previously operated components is first re-established, and then new components are properly setup with respect to the beam.

First, the Ion Source, RFQ and MEBT beams through the MEBT beam stop are prepared, following the established methods. The emphasis at this point is on reliable 20-25 mA source operation, rather than attempting to push the peak current. Once the MEBT beam is brought to the MEBT beam stop, the necessary MEBT measurements and tuning operations are performed. This work is carried out in major task 1.

Next beam is transported to the retractable beam stop after CCL4, and remaining MEBT portion and DTL tanks 1-6 are setup, as described in Task 2. The setting of the DTL phase and amplitude will follow the procedures established in the previous commissioning run. After the DTL portion is tuned, CCL modules 1-3 will be tuned using diagnostics upstream of the retractable beam stop and using established techniques. The Bunch Shpae Measurement (BSM) diagnostics in CCL1 will be exercised to examine the bunch length exiting the DTL.

After setting the CCL3, the retractable beam stop will be removed and beam will be transported to the linac beam dump. From this point on, the quadrupoles in the downstream region of the cavity being tuned will be periodically adjusted to accommodate the increasing beam energy, as tuning progresses. To this end, the quadrupoles in the SCL will be first set to 157 MeV values in order to transport the CCL3 energy beam to the linac beam dump. BPMs will be checked out and the trajectory corrected. CCL4 will then be tuned with PASTA and Delta-T methods, and the quadrupoles downstream of CCL4 will be set to values appropriate for the CCL4 exit energy of 185.6 MeV. Diagnostics in the SCL will be tested at this point before proceeding to the SCL cavity setup, and TOF measurements done to characterize theCCL4 exit beam energy.

Next tuning of the SCL cavities will begin. The cavity phase will be adjusted to match the desired value, but the amplitude will not be changed. Work will progress one cryomodule at a time. An important step in the SCL tuning will be to setup the LLRF feed forward beam loading compensation, which is expected to be a large effect in the SCL, and will be done before the phase setting techniques are applied. When setting the cavity phase the downstream cavities will be detuned first, to remove any complications introduced by beam loading effects on un-powered cavities. An RF phase scan will be done on the cavity, and results compared to a model, providing information on the RF phase setpoint, the RF amplitude and the entrance and exit beam energy to the cavity. Also, the drifting beam excitation of the cavity being tuned will provide an independent method to set the RF phase. Both these techniques will be employed. After the cavity is tuned, the trajectory to the linac dump will be checked.

The procedure outlined above will be repeated for each cavity. After tuning through cryomodules 1, 2, 3, 6, 9, and 11, new lattices values will be loaded to ensure that the beam remains adequately focused as the beam energy is increased. TOF measurements will be done after the medium and high beta sections to verify the energy of each section.

Next the transverse beam quantities will be verified. First the usual polarity checks will be performed for BPMs and correctors. Also transverse matching between the different lattice sections, and the linac dump will be checked using the wire profiles.

Then the SCL RF setup will be revisited with a more careful application of the drifting beam procedure, with a rigorous specification of beam energy, pulse shape, cavity resonance frequency and loaded Q, on a cavity by cavity basis, in order to calibrate the RF pickups. Pulse-to-pulse jitter experiments will be done.

Next time will be given to operation at 38 mA, higher rep rate operation, chopped beam testing, Differential Beam Current Monitor (DBCM) testing for Machine Protection System (MPS).

Finally, with time permitting, some accelerator physics experiments will be done, including round beam optics, the MEBT laser wire, automated SCL tuning application testing, and RFQ exit Twiss parameter characterization.

The remainder of this section presents the detailed instructions for carrying out the individual commissioning tasks.

3.1 PRESTART AND FRONT END OPERATION

3.1.1 Ion Source startup and cesiation

Follow the ion source startup procedure to produce a 20 mA beam.

3.1.2 Establish beam through RFQ

Insert the MEBT beamstop. Restore the nominal MEBT settings from the previous run. Set the MPS mode to 50 microseconds, the ion source pulse width to 100 microseconds and the repetition rate to 1 Hz. Observe the MEBT beam stop and BCM01 signals. Set the RFQ forward power to last run optimal set point and observe the current signals.

3.1.3 LEBT optimization

With beam safely transported to the beam stop, optimize the LEBT settings by observing the BCM01 signal. Measure the RFQ output beam intensity vs. source voltage and LEBT steering. Take an IS saveset at nominal conditions.

3.1.4 Measure RFQ transmission vs. excitation

With source and LEBT optimized for 50 usec, 20 mA, 1 Hz operation, record the BCM01 and beam stop current vs. RFQ forward power in the range 400 kW to 750 kW in 20 kW steps. Be sure to record both feedforward setpoint and forward power readback. Compare to previous measurements obtained from the front-end startup, and set RFQ power appropriately for maximum transmission. Take an IS/RFQ saveset at nominal conditions.

3.1.5 Iterate LEBT optimization and RFQ transmission

With RFQ at nominal power, retune LEBT for maximum transmission and maximum peak current on the MEBT beamstop. Take a saveset.

3.1.6 Check out MEBT BPMS #1-4

Generate 20 mA, 50 microsecond, 1 Hz beam. Observe beam position signals on BPMs 1-4. Adjust BPM timing as necessary. Tune correctors to verify change in beam position on MEBT BPMs.

3.1.7 Set phase of Rebunchers #1-2

With rebunchers set at nominal amplitude, check that the rebuncher LLRF phase and amplitude control loops are working properly. Verify that phase readback tracks command and that amplitude isn't affected and vice versa. Adjust feedback controls as necessary to achieve stable control. Use the MEBT Rebuncher Phase Scan program to find the bunching phase of Rebunchers 1-3. When finished, take a MEBT saveset. Note: Rebuncher 4 will be set in section 3.3.

3.1.8 Trajectory correction up to beam stop

Correct the MEBT trajectory using horizontal and vertical correctors. The trajectory error should be reduced below 1 mm. Record in the logbook the MEBT trajectory for LEBT steerers and MEBT correctors off, for LEBT steerers powered for optimum transmission and MEBT correctors off, and the corrected trajectory and the resulting corrector settings. Record a saveset.

3.1.9 Beam Envelope measurements and correction up to beam stop

Record beam profiles with wire scanners 1-3 to exercise the systems. Provide beam as necessary for the Diagnostics Group commissioning of the wire scanners. Measure the beam profiles up to the beam stop. Compare with the MEBT model. Derive RFQ output Twiss parameters from the model. Adjust quadrupole strengths as necessary to correct the beam envelopes. Record a saveset.

3.1.10 TOF RFQ Energy measurement

Perform Time-of-Flight measurements using MEBT BPMs to determine RFQ output beam energy.

3.1.11 LEBT Chopper test

Test the LEBT chopper performance using MEBT BPM pickups..

3.2 BEAM TRANSPORT THROUGH DTL

3.2.1 Set MEBT Rebunchers 3,4 phase and amplitude

Make sure MEBT gate valve to DTL Tank 1 is open. Remove MEBT beam stop and observe beam signals on BPMs 5 and 6 in MEBT. Beam will be stopped with the Energy degrader (ED) Faraday Cups (FC) in this commissioning portion. Insert DTL1 ED Faraday Cup. Perform phase scan of rebunchers 3 and 4 using the MEBT phase scan application. Calibrate the rebuncher voltage. Record the calibration constants and set rebunchers at bunching phase and nominal amplitude. Record a savest.

3.2.2 Correct MEBT trajectory

Correct the MEBT trajectory at BPMs 5 and 6 if necessary. Maintain trajectory error less than 1 mm.

3.2.3 Emittance measurement

Measure the DTL entrance emittance using the inline MEBT emittance measurement device.

3.2.4 Perform DTL1 Acceptance Scan

Insure the ED Farady cup after DTL1 is inserted and using 2-D DTL acceptance scan application find optimal phase and amplitude set point.

3.2.5 Perform DTL1 PASTA Analysis

Remove the ED Farady cup after DTL1, and insert ED Faraday Cup for DTL2, and using the Pasta application find the optimal phase and amplitude set point. Compare the results to that found in the acceptance scan and set DTL1 phase and amplitude accordingly. Take a save set.

3.2.6 Perform DTL2 Acceptance Scan

Insure the ED Farady cup after DTL2 is inserted and using 2-D DTL acceptance scan application find optimal phase and amplitude set point.

3.2.7 Perform DTL2 PASTA Analysis

Remove the ED Farady cup after DTL2, and insert ED Faraday Cup for DTL3, and using the Pasta application find the optimal phase and amplitude set point. Compare the results to that found in the acceptance scan and set DTL2 phase and amplitude accordingly. Take a save set.

3.2.8 Perform DTL3 Acceptance Scan

Insure the ED Farady cup after DTL3 is inserted and using 2-D DTL acceptance scan application find optimal phase and amplitude set point.

3.2.9 Perform DTL3 PASTA Analysis

Remove the ED Farady cup after DTL3, and insert ED Faraday Cup for DTL4, and using the Pasta application find the optimal phase and amplitude set point. Compare the results to that found in the acceptance scan and set DTL3 phase and amplitude accordingly. Take a save set.

3.2.10 Perform DTL4 Acceptance Scan

Insure the ED Farady cup after DTL4 is inserted and using 2-D DTL acceptance scan application find optimal phase and amplitude set point.

3.2.11 Perform DTL4 PASTA Analysis

Remove the ED Farady cup after DTL4, and insert ED Faraday Cup for DTL5, and using the Pasta application find the optimal phase and amplitude set point. Compare the results to that found in the acceptance scan and set DTL4 phase and amplitude accordingly. Take a save set.

3.2.12 Perform DTL5 Acceptance Scan

Insure the ED Farady cup after DTL5 is inserted and using 2-D DTL acceptance scan application find optimal phase and amplitude set point.

3.2.13 Perform DTL5 PASTA Analysis

Remove the ED Farady cup after DTL5, and insert ED Faraday Cup for DTL6, and using the Pasta application find the optimal phase and amplitude set point. Compare the results to that found in the acceptance scan and set DTL5 phase and amplitude accordingly. Take a save set.

3.2.14 Perform DTL6 Acceptance Scan

Insure the ED Farady cup after DTL6 is inserted and using 2-D DTL acceptance scan application find optimal phase and amplitude set point.

3.2.15 Trajectory corrections

Correct the trajectory in the DTL using the orbit correction application and take a save set.

3.2.16 LLRF tuning for beam loading

Provide beam time to LLRF to optimize the LLRF feed forward parameters for robustness.

3.2.17 Wire Scan for the MEBT and DTL

Take a full set of wire profile measurements using the wire profile application.

3.2.18 TOF energy measurements

Perform TOF beam energy measurements after DTL tanks 1,2,3,4 and 5.

3.3 BEAM TRANSPORT THROUGH CCL TO THE RETRACTABLE BEAM STOP

3.3.1 PASTA Analysis for DTL6

Ensure that the retractable beam stop is inserted, that all ED Faraday cups are retracted, and that all CCL quadrupole magnets are properly set. Use the Pasta application to find the proper phase and amplitude set points. Compare the results to that found in the acceptance scan and set DTL6 phase and amplitude accordingly. Take a save set.

3.3.2 PASTA Analysis for CCL1

Use the Pasta application to find the proper CCL1 phase and amplitude set points.

3.3.3 Delta-T tune for CCL1

Use the results of the above Pasta analysis as a starting point for the Delta-T application to set the CCL1 phase and amplitude. Take a save set.

3.3.4 BSM measurements in CCL1

Take Bunch Shape Measurements (BSM) in CCL1, and compare results to model predictions. If there is a discrepancy, adjust DTL6 settings and repeat.

3.3.5 PASTA Analysis for CCL2

Use the Pasta application to find the proper CCL2 phase and amplitude set points.

3.3.6 Delta-T tune for CCL2

Use the results of the above Pasta analysis as a starting point for the Delta-T application to set the CCL2 phase and amplitude. Take a save set.

3.3.7 PASTA Analysis for CCL3

Use the Pasta application to find the proper CCL1 phase and amplitude set points.

3.3.8 Delta-T tune for CCL3

Use the results of the above Pasta analysis as a starting point for the Delta-T application to set the CCL3 phase and amplitude. Take a save set.

3.3.9 Set up ion source for CCL4, SCL tuning

A 10 mA, 20 μsec beam pulse will be set up for the initial commissioning. The beam limiting aperture in the MEBT will be inserted, and the ion source tuned to produce a flat pulse over the short pulse length. The diagnostic timing gates will be checked to be consistent with this pulse length.

3.4 BEAM TRANSPORT THROUGH SCL TO LINAC DUMP

3.4.1 Load 157 MeV SCL, HEBT and Linac Dump quadupole settings

Load the 157 Mev (CCL3 exit energy) lattice settings and remove the retractable beam stop

3.4.2 Correct the Trajectory

Provide beam, and correct the trajectory throughout the SCL , HEBT and linac dump line.

3.4.3 Checkout SCL , HEBT and linac dump line BPMs

3.4.4 Checkout SCL , HEBT and linac dump line BLMs

3.5 TUNEUP CCL4

3.5.1 Perform Pasta Analysis on CCL4

Summon an RCT to verify shielding. Using the initial SCL BPMs, perform a Pasta analysis of CCL4 to obtain initial phase and amplitude setpoints.

3.5.2 Delta-T Tune for CCL4

Use the results of the above Pasta analysis as a starting point for the Delta-T application to set the CCL4 phase and amplitude. Take a save set.

3.5.3 Load 186 Mev SCL, HEBT and Linac Dump quadupole settings

Load the 186 Mev (CCL4 exit energy) lattice settings and verify the trajectory to the linac dump is satisfactory. If not apply the orbit correction application.

3.5.4 Perform 186 MeV fault study

Perform the 186 MeV fault study as per the fault study plan.

3.6 SCL INPUT BEAM CHARATERIZATION

3.6.1 TOF Measurements

Perform TOF beam energy measurements after CCL Modules 1,2,3 and 4.

3.6.2 Transverse Beam Size

Take wire scan measurements throughout the CCL and compare to the model predictions. .

3.6.3 Warm linac loss measurents

Using the BLMs in the warm linac to characterize the loss pattern throughout the warm linac.

3.7 SCL AND HEBT DIAGNOSTIC CHECKOUT

3.7.1 Continue BLM checkout

Checkout the BLMs in the SCL, HEBT and Linac Dump lines.

3.7.2 SCL Laser Wire checkout.

Commission the SCL laser wire systems.

3.7.3 Linac Dump wire scanner checkout

Verify the linac dump wire scanner is working properly, and that the beam is centered on the linac dump.

3.7.4 Check BPM and corrector polarities.

Use the orbit difference application to verify BPM and corrector polarities and calibrations throughout the SCL and HEBT.

3.7.5 Setup SCL_Diag:BPM0 8 and SCL_Diag:BPM09 for TOF

Prepare BPMs near the end of the medium beta SCL section for TOF energy measurements.

3.7.6 Setup SCL_Diag:BPM23 and SCL_Diag:BPM25 for TOF

Prepare BPMs in the high beta SCL section for TOF energy measurements.

3.8 SCL MEDIUM BETA TUNEUP

3.8.1 Detune all SCL cavities

Detune all SCL cavities, except the first cavity in medium beta cryomodule 1, by 30 kHz using the mechanical tuners.

3.8.2 Setup BPMs for CM1 phase scan

BPMs after cryomodule 1 and after cryomodule 2 will be used for setting the phase of cavities 1a, 1b and 1c. The proper functionality of the phase measurements from these BPMs will be checked with the beam.

3.8.3 SCL medium beta cryomodule 1 tune

The tuning of each cryo-module will progress one cavity at a time.

First the phase setpoint of cavity SCL_RF:Cav01a using the drifting beam application will be noted, with the cavity unpowered. Next the LLRF feed-forward settings for this cavity will be adjusted to provide a stable field and phase throughout the pulse. Then the SCL phase scan application will be run for this cavity, at the design field setting to calculate the phase setpoint, cavity field and beam input energy. The phase of cavity SCL_RF:Cav01a will be set using the drifting beam and phase scan results.

Then cavity SCL_RF:Cav01b will be returned to design frequency and it will be set. First SCL_RF:Cav01b phase setpoint from the drifting beam application is found, and then LLRF will setup its feed-forward parameters. Next the SCL phase scan application will be run for this cavity, at the design field setting to calculate the phase setpoint, cavity field and beam input energy. The phase of cavity SCL_RF:Cav01b will be set using the drifting beam and phase scan results.

Then cavity SCL_RF:Cav01c will be returned to design frequency and it will be set. First SCL_RF:Cav01c phase setpoint from the drifting beam application is found, and then LLRF will setup its feed-forward parameters. Next the SCL phase scan application will be run for this cavity, at the design field setting to calculate the phase setpoint, cavity field and beam input energy. The phase of cavity SCL_RF:Cav01c will be set using the drifting beam and phase scan results.

The exit energy from medium beta cryomodule 1 will be checked with TOF.

The beam trajectory to the linac dump will be checked and corrected if necessary.

3.8.4 Setup BPMs for CM2 phase scan

BPMs after cryomodule 2 and after cryomodule 3 will be used for setting the phase of cavities 2a, 2b and 2c. The proper functionality of the phase measurements from these BPMs will be checked with the beam.

3.8.5 Load 200 MeV lattice settings

Load the 200 Mev (cryomodule 1 exit energy) lattice settings and verify the trajectory to the linac dump is satisfactory. If not apply the orbit correction application.

3.8.6 Tune cryo modules 2-11

The cavity tuning procedure (3.82-3.8.4) will be repeated for each of the SCL medium beta cryomodules consecutively. After the following cryomodules, the lattice will be updated for the respective exit energies and TOF measurements taken:

After cryomodule 2 – lattice quadrupole setup for 225 MeV
After cryomodule 3 – lattice quadrupole setup for 260 MeV
After cryomodule 6 – lattice quadrupole setup for 340 MeV
After cryomodule 9 – lattice quadrupole setup for 414 MeV
After cryomodule 11 – lattice quadrupole setup for 451 MeV

3.8.29 Perform the 387 MeV Fault study

Perform the 387 MeV fault study, as per the fault study plan.

3.9 SCL HIGH BETA TUNEUP

3.9.1 Setup BPMs for CM12 phase scan

BPMs after cryomodule 12 and after cryomodule 13 will be used for setting the phase of cavities 12a, 12b, 12c and 12d. The proper functionality of the phase measurements from these BPMs will be checked with the beam.

3.9.2 SCL high beta cryomodule 12 tune

First the phase setpoint of cavity SCL_RF:Cav12a using the drifting beam application will be noted, with the cavity unpowered. Next the LLRF feed-forward settings for this cavity will be adjusted to provide a stable field and phase throughout the pulse. Then the SCL phase scan application will be run for this cavity, at the design field setting to calculate the phase setpoint, cavity field and beam input energy. The phase of cavity SCL_RF:Cav12a will be set using the drifting beam and phase scan results.

Then cavity SCL_RF:Cav012b will be returned to design frequency and it will be set. First SCL_RF:Cav12b phase setpoint from the drifting beam application is found, and then LLRF will setup its feed-forward parameters. Next the SCL phase scan application will be run for this cavity, at the design field setting to calculate the phase setpoint, cavity field and beam input energy. The phase of cavity SCL_RF:Cav12b will be set using the drifting beam and phase scan results.

Then cavity SCL_RF:Cav12c will be returned to design frequency and it will be set. First SCL_RF:Cav12c phase setpoint from the drifting beam application is found, and then LLRF will setup its feed-forward parameters. Next the SCL phase scan application will be run for this cavity, at the design field setting to calculate the phase setpoint, cavity field and beam input energy. The phase of cavity SCL_RF:Cav12c will be set using the drifting beam and phase scan results.

Then cavity SCL_RF:Cav12d will be returned to design frequency and it will be set. First SCL_RF:Cav12d phase setpoint from the drifting beam application is found, and then LLRF will setup its feed-forward parameters. Next the SCL phase scan application will be run for this cavity, at the design field setting to calculate the phase setpoint, cavity field and beam input energy. The phase of cavity SCL_RF:Cav12d will be set using the drifting beam and phase scan results.

The exit energy from medium beta cryomodule 1 will be checked with TOF.
The beam trajectory to the linac dump will be checked and corrected if necessary.

3.9.3 Tune high beta cryomodules 13-22

The cavity tuning procedure (3.9.1-3.9.2) will be repeated for each of the SCL high beta cryomodules consecutively. After cryomodules 14, 17, 20 and 22 TOF measurements will be taken. After cryomodule 16 the lattice quadrupole settings for 680 MeV will be loaded.

3.9.24 High energy fault study

After the beam is tuned to full energy, the high energy fault study will be performed as per the fault study plan.

3.10 TRANSVERSE MATCHING IN THE SCL

3.10.1 Match the various lattice sections

Take profile measurements in the SCL medium beta section, and compare to the model predictions. If there appears to be a mismatch, adjust the matching quadrupoles before cryomodule 1 and repeat

Take profile measurements throughout the start of the SCL high beta section and HEBT, and compare to the model predictions. If there appears to be a mismatch, adjust the matching quadrupoles after cryomodules 10 and 11 and repeat.

Take profile measurements throughout the HEBT and linac dump, and compare to the model predictions. If there appears to be a mismatch, adjust the matching quadrupoles HEBT_Mag:QV01 and HEBT_Mag:QH02.

3.10.2 Check the SCL exit profiles

Use the SCL exit laser wire system to check the beam profiles at the exit of the SCL linac.

3.11 HEBT AND LINAC DUMP TUNEUP

3.11.1 Measure Linac dump profile

Use the linac dump wire scanner to measure the beam profile in the linac dump line and compare to predicted beam size.

3.11.2 Check and correct the trajectory

Check the beam trajectory, and if needed use the orbit correction application to correct the orbit in the HEBT and Linac dump.

3.11.3 Explore the HEBT collimation

Lets go spelunking.

3.11.4 Check BPM and corrector polarities.

Use the orbit difference application to verify BPM and corrector polarities and calibrations throughout the SCL and HEBT.

3.12 FAULT STUDIES

Any remaining fault studies will be done, in accordance with the fault study plan.

3.13 SCL TUNEUP COMPARISON: DRIFTING BEAM VS. PHASE SCAN

The steps involved in sections 3.8 and 3.9 involved using the drifting beam technique to determine RF phase setpoints. In the section the drifting beam application will be applied to try and determine the cavity field as well. This requires a good knowledge of the beam energy, cavity Q_L, and beam pulse shape. Similar to the techniques described in sections 3.8, and 3.9, the SCL tune-up with the drifting beam technique will progress one cryomodule at a time. We will start with all cavities tuned off resonance, and un-powered.

3.13.1 Establish LLRF signals from drifting beam

Cavity SCL_Rf:Cav01a will be brought on resonance, and the drifting beam application applied, with careful input for the beam energy, cavity Q_L, and beam pulse shape providing the cavity field and phase information.

3.13.2 Compare to phase scan results

Results from this drifting beam technique will be compared to the previously taken data.

3.13.3 Phase scan with cavity on resonance

If the drifting beam and previous phase scan results differ, the phase scan result will be repeated with the cavity on resonance.

3.13.4 Calibrate pickup probe for amplitude

The LLRF amplitude signal will be calibrated to agree with the measured cavity amplitude from the above drifting beam and phase scan results.

3.13.5 Refine the RF as needed

If the RF amplitude has changed by more than a few percent, the phase setpoint will be adjusted as needed to provide a constant focusing setting.

3.13.6 Drifting beam tune-up for rest of SCL

The procedures described in 3.13.1-3.13.5 will be applied to each useful SCL cavity, consecutively.

3.14 CHARATERIZE 1 GEV OUTPUT BEAM QUALITY

3.14.1 Measure Energy and position jitter

The beam energy and position jitter will be analyzed at several points at the end of the SCL. BPM position and phase measurements will be monitored and saved over an extended period (e.g. 1-2 hours) for analysis. This includes average values over a macro-pulse, as well as wave form arrays during the pulse.

3.14.2 SCL exit emittance estimate

The beam emittance at the SCL exit will be estimated using the last laser wire in the SCL as well as the HEBT wire scanners (with the AOC application).

3.15 ACHIEVE PRODUCTION BEAM PARAMETERS

3.15.1 Tuneup for nominal 38 mA peak cuuent

Insert the MEBT beam stop and increase the beam current to 38 mA. Adjust the lattice parameters for 38 mA operation. Remove the beam stop. Take a complete set of wire profiles and CCL BSM measurements.

3.15.2 Adjust for higher rep-rate

Increase the rep rate to $\leq$ 30 Hz.

3.15.3 Jitter analysis at high rep rate

Monitor and record ~ 1000 consequtive BPM position and phase measurements throughout the SCL at high rep rate.

3.15.4 Chopped beam demonstration

Verify the LEBT and MEBT beam chopper works at a high rep rate.

3.16 PHYSICS EXPERIMENTS

3.16.1 Loss study with matching

Monitor the beam loss signals as matching quadrupoles are adjusted in the matching sections of the MEBT, SCL to SCL, SCL medium beta to high beta, and SCL to HEBT interfaces.

3.16.2 Test the energy management application

Use the energy management application to predict new cavity amplitude and phase setpoints as well as quadrupole settings to achieve a given beam output energy, for various fault conditions.

3.16.3 MEBT laser wire

3.16.4 MEBT Scrapper Experiment

Insert the MEBT scrapers and take a complete set of profile measurements downstream with and without scraping. .

3.16.5. CCL_Mag:QH01 sensitivity

Perform wire scans throughout the warm linac for several CCL_Mag:QH01 settings to investigate a question of the field mapping for this magnet.

3.16.6. RFQ exit twiss study

Perform wire scans throughout the MEBT for MEBT quads 1-10 each varied independently by -10%.

3.16.7. Round beam optics

Perform wire scans throughout the warm linac for the round beam optics lattice.

APPENDIX A. CCL MODULE FOUR AND SCL MEDIUM AND HIGH BETA CRYOMODULE SECTION BEAM COMMISSIONING TASKS

	TASK	Duration (shifts)	Peak Current (mA)	Pulse Width (usec)	Rep Rate (Hz)	Beam Power (kW)	Beam stop	Priority	Beam Energy [MeV]
1	**Pre-start Front-End Operation**	11.0	20	50	2	0.005	MEBT	1	
1.1	Ion source start up and cesiation (20 mA)	0.5							2.5
1.2	Establish beam through RFQ	0.5							2.5
1.3	LEBT optimization	0.5							2.5
1.4	Measure RFQ transmission vs. excitation	0.5							2.5
1.5	Iterate LEBT optimization/RFQ transmission	0.3							2.5
1.6	Diagnostics checkout	0.5							2.5
1.7	Phase set of rebunchers ##1-2	0.5							2.5
1.8	Trajectory correction up to beam stop	0.3							2.5
1.9	Beam envelope measurements and correction up to beam stop	0.5							2.5
1.10	TOF measurement of RFQ energy	0.5							2.5
1.11	Chek-out LEBT chopper (blank off only)	0.5							
2	**Beam transport through DTL**	5.0	10	20	1	0.0005		1	
2.1	Set MEBT rebuncher 3, 4 phase and amplitude	0.3					EDFC -1		
2.2	Correct MEBT trajectory	0.3					EDFC -1		
2.3	Measure emittance	0.5							
2.4	Perform Acceptance Scan with Energy Degrader/Faraday Cup a	0.3					EDFC -1		
2.5	PASTA scan for DTL1	0.3					EDFC -1		
2.6	Perform Acceptance Scan with Energy Degrader/Faraday Cup a	0.3					EDFC -2		
2.7	PASTA scan for DTL2	0.3					EDFC -2		
2.8	Perform Acceptance Scan with Energy Degrader/Faraday Cup a	0.3					EDFC -3		
2.9	PASTA scan for DTL3	0.3					EDFC -3		
2.10	Perform Acceptance Scan with Energy Degrader/Faraday Cup a	0.3					EDFC -4		
2.11	PASTA scan for DTL4	0.3					EDFC -4		
2.12	Perform Acceptance Scan with Energy Degrader/Faraday Cup a	0.3					EDFC -5		
2.13	PASTA scan for DTL5	0.3					EDFC -5		
2.14	Perform Acceptance Scan with Energy Degrader/Faraday Cup a	0.3					EDFC -6		
2.15	Trajectory correction	0.3					EDFC-6		
2.16	LLRF tuning for beam loading	0.3					EDFC-6		
2.17	Wire scan MEBT + all DTLs	0.3					EDFC-6		
2.18	TOF energy measurement after DTL1, DTL2, DTL3,DTL4,DTL5	0.5					EDFC-6		
3	**Beam transport through CCL to Transition Beamstop**	2.3	10	20	1		TBS	1	
3.1	PASTA scan for DTL6	0.3				0.087			87
3.2	PASTA scan for CCl1	0.3							
3.3	Perform delta-T scan and tune amplitude and phase CCL1	0.3				0.0214			107

3.4	BSM measurements in CCL1	0.3							
3.5	PASTA scan for CCl2	0.3							
3.6	Perform delta-T scan and tune amplitude and phase CCL2	0.3				0.131			131
3.7	PASTA scan for CCl3	0.3							
3.8	Perform delta-T scan and tune amplitude and phase CCL3	0.3				0.157			157
3.9	Tune Ion Source for 10 mA, 20 μsec	0.3							
4	**Beam transport through SCL to Linac Dump**	1.8	10	20	1	0.0314	Ldmp	1	157
4.1	Load 157 MeV SCL and HEBT lattice	0.5							
4.2	Correct trajectory	0.3							
4.3	Checkout SCL & HEBT BPMs	0.5							
4.4	Checkout SCL & HEBT BLMs	0.5							
5	**Tuneup CCL-4**	2.0	10	20	1	0.0372	Ldmp	1	186
5.1	Perform delta-T scan and tune amplitude and phase CCL4	0.3							
5.2	PASTA scan for CCL4	0.3							
5.3	Load 186 MeV SCL and HEBT lattice	0.5							
5.4	Perform 186 MeV Fault study	1.0							
6	**SCL Input Beam Characterization**	1.3	10	20	1	0.0372	Ldmp	1	186
6.1	TOF energy measurement after CCL1, 2, 3, 4	0.5							
6.2	Wire scans in CCL1-4	0.5							
6.3	Loss measurements in warm linac	0.3							
7	**Diagnostics Checkout in SCL & HEBT**	5.5	10	20	1	0.0372	Ldmp	1	186
7.1	Continue BLM checkout	1.0							
7.2	Checkout SCL LWS	2.0							
7.3	Ldump Wire Scanner checkout	0.5							
7.4	BPM and corrector polaity check	1.0							
7.5	Setup BPMs in MB8 - MB9 for TOF measurement	0.5							
7.6	Setup BPMs in HB12 - HB14 for TOF measurement	0.5							
8	**SCL Medium Beta Tuneup**	22.2	10	20	1		Ldmp	1	
8.1	Detune all SCL cavities by 30 kHz	0.5							
8.2	Setup BPMS for CM1 phase scan	0.5							
8.3	Perform CM1 phase scan and establish RF setpoints	0.5	10	20	1	0.04			200
	Check linac energy with TOF	0.2							
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM1 cavities for beam-loading	0.5							

8.4	Load SCL/HEBT lattice for 200 MeV	0.1					
8.5	Setup BPMs for CM2 phase scan	0.5					
8.6	Perform CM2 phase scan and establish RF setpoints	0.5	10	20	1	0.0434	217
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM2 cavities for beam-loading	0.5					
8.7	Setup BPMs for CM3 phase scan	0.5					
8.8	Perform CM3 phase scan and establish RF setpoints	0.5	10	20	1	0.047	235
8.9	Load SCL/HEBT lattice for 235 MeV	0.5					
	Check linac energy with TOF	0.2					
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM3 cavities for beam-loading	0.5					
8.10	Setup BPMs for CM4 phase scan	0.5					
8.11	Perform CM4 phase scan and establish RF setpoints	0.5	10	20	1	0.0508	254
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM4 cavities for beam-loading	0.5					
8.12	Setup BPMs for CM5 phase scan	0.5					
8.13	Perform CM5 phase scan and establish RF setpoints	0.5	10	20	1	0.055	275
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM5 cavities for beam-loading	0.5					
8.14	Setup BPMs for CM6 phase scan	0.5					
8.15	Perform CM6 phase scan and establish RF setpoints	0.5	10	20	1	0.059	295
8.16	Load SCL/HEBT lattice for 295 MeV	0.5					
	Check linac energy with TOF	0.2					
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM6 cavities for beam-loading	0.5					
8.17	Setup BPMs for CM7 phase scan	0.5					
8.18	Perform CM7 phase scan and establish RF setpoints	0.5	10	20	1	0.063	315
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM7 cavities for beam-loading	0.5					
8.19	Setup BPMs for CM8 phase scan	0.5					
8.20	Perform CM8 phase scan and establish RF setpoints	0.5	10	20	1	0.067	335
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM8 cavities for beam-loading	0.5					
8.21	Setup BPMs for CM9 phase scan	0.5					
8.22	Perform CM9 phase scan and establish RF setpoints	0.5	10	20	1	0.0708	354
8.23	Load SCL/HEBT lattice for 354 MeV	0.5					
	Check linac energy with TOF	0.2					
	Check/Adjust trajectory	0.1					
	LLRF Tuneup of CM9 cavities for beam-loading	0.5					
8.24	Setup BPMs for CM10 phase scan	0.5					
8.25	Perform CM10 phase scan and establish RF setpoints	0.5	10	20	1	0.0746	373

	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM10 cavities for beam-loading	0.5							
8.26	Setup BPMs for CM11 phase scan	0.5							
8.27	Perform CM11 phase scan and establish RF setpoints	0.5	10	20	1	0.0782			391
8.28	Load SCL/HEBT lattice for 391 MeV	0.5							
	Check/Adjust trajectory	0.1							
	Check linac energy with TOF	0.2							
	LLRF Tuneup of CM11 cavities for beam-loading	0.5							
8.29	Perform 391 MeV fault study	1.0							
9	**SCL High Beta Tuneup**	19.7	10	20	1		Ldmp	1	
9.1	Setup BPMS for CM12 phase scan	0.5							
9.2	Perform CM12 phase scan and establish RF setpoints	0.5	10	20	1	0.0852			426
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM12 cavities for beam-loading	0.5							
9.3	Setup BPMs for CM13 phase scan	0.5							
9.4	Perform CM13 phase scan and establish RF setpoints	0.5	10	20	1	0.0932			466
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM13 cavities for beam-loading	0.5							
9.5	Setup BPMs for CM14 phase scan	0.5							
9.6	Perform CM14 phase scan and establish RF setpoints	0.5	10	20	1	0.1022			511
	Check linac energy with TOF	0.2							
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM14 cavities for beam-loading	0.5							
9.7	Setup BPMS for CM15 phase scan	0.5							
9.8	Perform CM15 phase scan and establish RF setpoints	0.5	10	20	1	0.1118			559
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM15 cavities for beam-loading	0.5							
9.9	Setup BPMs for CM16 phase scan	0.5							
9.10	Perform CM16 phase scan and establish RF setpoints	0.5	10	20	1	0.1222			611
9.11	Load SCL/HEBT lattice for 611 MeV - 1 GeV	0.5							
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM16 cavities for beam-loading	0.5							
9.12	Setup BPMs for CM17 phase scan	0.5							
9.13	Perform CM17 phase scan and establish RF setpoints	0.5	10	20	1	0.1328			664
	Check linac energy with TOF	0.2							
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM17 cavities for beam-loading	0.5							
9.14	Setup BPMS for CM18 phase scan	0.5							
9.15	Perform CM18 phase scan and establish RF setpoints	0.5	10	20	1	0.144			720
	Check/Adjust trajectory	0.1							

	LLRF Tuneup of CM18 cavities for beam-loading	0.5							
9.16	Setup BPMs for CM19 phase scan	0.5							
9.17	Perform CM19 phase scan and establish RF setpoints	0.5	10	20	1	0.1552			776
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM19 cavities for beam-loading	0.5							
9.18	Setup BPMs for CM20 phase scan	0.5							
9.19	Perform CM20 phase scan and establish RF setpoints	0.5	10	20	1	0.1664			832
	Check linac energy with TOF	0.2							
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM20 cavities for beam-loading	0.5							
9.20	Setup BPMS for CM21 phase scan	0.5							
9.21	Perform CM21 phase scan and establish RF setpoints	0.5	10	20	1	0.1776			888
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM21 cavities for beam-loading	0.5							
9.22	Setup BPMs for CM22 phase scan	0.5							
9.23	Perform CM22 phase scan and establish RF setpoints	0.5	10	20	1	0.189			945
	Check/Adjust trajectory	0.1							
	LLRF Tuneup of CM22 cavities for beam-loading	0.5							
9.24	Perform high energy fault study	1.0							
10	**Transverse matching in SCL**	4.0	10	20	1	0.2	Ldmp	1	1000
10.1	Match CCL to SCL Medium-Beta	1.0							
	Match SCL Medium to High-Beta	1.0							
	Match SCL High-Beta to HEBT	1.0							
10.2	Check profiles at SCL exit with LWS	1.0							
11	**HEBT and Linac Dump Tuneup**	3.7	10	20	1	0.2	Ldmp	1	1000
11.1	Measure Ldmp profile	0.2							
11.2	Check/correct trajectory	0.5							
11.3	Explore HEBT Collimation	1.0							
11.4	Check Corrector and BPM polarities and calibration (SCL&HEB	2.0							
12	**Fault Studies**	1.0	10	20	1	0.2	Ldmp	1	1000
	Perform Fault Study Plan	1.0							
13	**SCL Tuneup Comparison, Drifting Beam vs. Phase Scan**	18.0	20	50	1	1	Ldmp	1	1000
13.1	Tuneup 20 mA, 50 micro-sec beam, retune SCL as required	4.0							
13.2	Establish LLRF signals from drifting beam	1.0							
13.3	Measure beam phase from drifting beam & compare w/ phase s	4.0							
13.4	Measure phase scan with cavity On-resonance and compare	2.0							
13.5	Calibrate pickup probes for amplitude	5.0							

13.6	Refine RF setpoints as needed	2.0							
14	**Characterize 1 GeV output beam quality**	2.0	20	50	1	1	Ldmp		1000
14.1	Measure energy and position jitter pulse to pulse and within a pı	1.0						1	
14.3	Emittance estimate from last SCL LWS	1.0						2	
15	**Achieve Production Beam Parameters (independently)**	7.0					Ldmp		
15.1	Tuneup nominal 38mA peak current	3.0	38	50	1	1.9		1	1000
15.2	High-rep rate, short pulse operation	2.0	20	35	10	7		2	1000
15.3	Measure pulse-to-pulse jitter in high-rep rate operation	1.0	20	35	10	7		2	1000
15.4	Chopped beam demonstration	1.0	38	50	1	1.9		1	1000
16	**Other Accelerator Physics Studies**	6.5	20	50	1	1	Ldmp	2	1000
16.1	Loss study with matching	1.0							
16.2	Test energy management application	3.0							
16.3	Test MEBT "laser wire"	1.0							
16.4	MEBT scraper experiment	0.5							
16.5	Study CCL_QH102 B(I) using wires	0.5							
16.6	RFQ exit Twiss study	0.5							
16.7	"Round optics" experiment	0.5							
		116.9							
	Total Days	39.0							